ER/WM&I DDT

Source/Driver: (Name & Number from ISP, IAG milestone, Mgmt. Action, Corres. Control, etc.)

Closure #: (Outgoing Correspondence Control #, if applicable)

Due Date

A. L. Primrose
Originator Name

G. DiGregorio for
QA Approval

J. E. Law
Contractor Manager(s)

L. Butler
Kaiser-Hill Program Manager(s)

A. D. Rodgers
Kaiser-Hill Director

Document Subject:

TRANSMITTAL OF **"CONCEPTUAL MODEL FOR HYDROGEOLOGIC EVALUATION OF REMEDIAL ALTERNATIVES FOR THE SOLAR PONDS PLUME, RF/RMRS-98-238.UN"** - JEL-123-98

KH-00003NS1A July 17, 1998

Discussion and/or Comments:

Enclosed please find ten (10) copies the ***"Conceptual Model for Hydrogeologic Evaluation of Remedial Alternatives for the solar Ponds Plume, RF/RMRS-98-238.UN,"*** dated June 16, 1998. Three (3) copies of the document are for Kaiser-Hill and seven (7) copies are for transmittal to Doe (three copies), the EPA (two copies), and the CDPHE (two copies).

If you have any questions regarding this document please contact Annette Primrose at extension 4385 or Kelly Hranac at extension 7400.

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A. C. Crawford
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Remediation Services, L.L.C.
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CONCEPTUAL MODEL FOR HYDROGEOLOGIC EVALUATION OF REMEDIAL ALTERNATIVES FOR THE SOLAR PONDS PLUME

RF/RMRS-98-238.UN

Environmental Restoration
Rocky Flats Environmental Technology Site

July 16, 1998

Conceptual Model for Hydrogeologic Evaluation of Remedial Alternatives for the Solar Ponds Plume

June 16, 1998

prepared by

Rocky Mountain Remediation Services, L.L.C.

Rocky Flats Environmental Technology Site

Golden, Colorado

Responsible Manager

for G. DiGregorio

Quality Assurance

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EXECUTIVE SUMMARY

The Solar Ponds Plume (SPP) comprises a zone of contaminated groundwater, containing chiefly dissolved nitrate and uranium, that has been identified in an area north of the former Solar Evaporation Ponds (SEPs) at Rocky Flats Environmental Technology Site (RFETS). Four remedial alternatives are being considered in the selection of the final remedy for the SPP. This report presents the conceptual hydrogeologic model for the SPP, and describes the program of remedial alternatives analysis that will be performed to evaluate the four alternatives.

The SEPs are located in the northeast corner of RFETS overlooking a relatively steep hillslope that declines approximately 110 feet to North Walnut Creek. North Walnut Creek flows from west to east, and is located approximately 1,000 feet to the north of the SEPs. The SPP extends primarily northeastward from the SEPs to North Walnut Creek, with a localized lobe extending southeast from the ponds toward a small swale that forms the headwaters of South Walnut Creek. Groundwater flows slowly in a thin layer of saturation in the hillslope alluvium, and in the fractured upper portion of the underlying bedrock.

Elevated concentrations of nitrate and uranium in groundwater have been observed in both the alluvium and upper weathered bedrock zones in the larger northeast portion of the plume. The plume is confined to the upper portions of the flow system by underlying competent bedrock of low permeability, and by the hydraulic flow patterns induced by discharge of shallow groundwater to North Walnut Creek.

The Interceptor Trench System (ITS), was installed in the alluvium of the hillslope to the north of the SEPs to capture the SPP prior to groundwater discharge to North Walnut Creek. The ITS is completed a short distance into (ie. keyed into) the upper fractured bedrock along most of its length, but some contaminated groundwater reaches North Walnut Creek via flow under the ITS in areas where it is not keyed to bedrock. The effectiveness of the trench system in capturing groundwater in the upper bedrock has not been completely determined.

The four remedial alternative scenarios that will be evaluated are: (1) baseline conditions (no ITS, and no SEP cap), (2) existing ITS (with SEP cap added in 2005), (3) enhanced ITS (with SEP cap added in 2005), and (4) phytoremediation. Analyses will be conducted for each of the scenarios to provide RFETS with information on ITS extraction rate, groundwater levels, groundwater fluxes, and groundwater quality. Sensitivity analyses will be performed for key parameters, and analyses will be conducted for future conditions associated with phased RFETS closure.

One- and two-dimensional computer models will be used to analyze the future performance of the remedial alternative scenarios. Appropriate simplifications will be made to the SPP flow system to streamline the analyses and to support relative comparisons of the identified scenarios. Groundwater flow models will be used to calculate the ITS extraction rate, groundwater levels within the SPP hillslope aquifer system, and fluxes of groundwater within the aquifer and to nearby surface water bodies. Plume flushing models or simple mass transport models will be used to calculate water quality (nitrate and uranium) within the hillslope aquifer, with a focus on the groundwater zone immediately adjacent to North Walnut Creek. Soil zone models will be used, if necessary, to calculate infiltration for various hydrologic conditions or to examine vertical water and dissolved mass movement in the unsaturated zone.

A first phase of screening analyses will be conducted to define a subset of remedial alternative scenarios to be carried forward for more detailed evaluation. In phase two, models will be refined and model linkages will be enhanced to provide additional accuracy and detail in the analysis results. Upon completion of the phase two calculations for selected scenarios, sensitivity analyses will be conducted for key parameters within each selected scenario. The results of the alternatives analyses and sensitivity analyses will be provided to RFETS in an alternatives analysis report.

1 INTRODUCTION AND SITE DESCRIPTION

Rocky Flats Environmental Technology Site (RFETS) is located approximately 16 miles northwest of Denver, Colorado on 6,550 acres of federally-owned land. RFETS began operations in 1952 as part of the U.S. government nuclear weapons research, development, and production effort. Production operations at the site included nuclear weapons parts manufacture, recovery and purification of transuranic radionuclides, along with research and development programs. These activities took place in a centrally-located industrial area (IA), 400 acres in size, surrounded by a 6,150-acre buffer zone (Figure 1). Operations within the IA have generated many types of nonhazardous, hazardous, and radioactive wastes that have been disposed of in a variety of ways. Nonhazardous, nonradioactive wastes were disposed in a landfill on-site, while hazardous and/or radioactive wastes were either recycled, stored on-site, or shipped off-site for processing or disposal.

The Solar Evaporation Ponds (SEPs) located in the northeast corner of the IA were part of the waste management system at RFETS designed to store and concentrate liquid wastes from industrial processes at the site (Figure 2). The focus of this document is to develop a conceptual model for the evaluation of remedial alternatives for groundwater contamination arising from historic operations of the SEPs.

1.1 Solar Ponds and Solar Ponds Plume

The SEPs consist of 5 shallow, asphalt-lined ponds, referred to as 207-A; 207-B north, middle and south; and 207-C. The ponds cover an area of approximately 294,000 square feet and extend to a depth approximately 5 feet below the elevations of the surrounding berms. They are clustered together and situated on a topographic high in the northeast corner of the IA at an elevation of approximately 5,970 feet above mean sea level. The topographic high is flanked by hillslopes leading to small creeks, North Walnut Creek to the northeast, and South Walnut Creek to the southeast (Figure 2). Plumes of contaminated groundwater, originating at the SEPs are migrating toward each of the creeks, with the larger plume moving toward the northeast to North Walnut Creek. The primary constituents of the plumes are nitrate and uranium radionuclides.

Disposal activities in the SEP area began with the installation of an evaporation pond (Pond 2) in October 1953 in the northeast corner of the IA. Pond 2 was constructed at the current location of

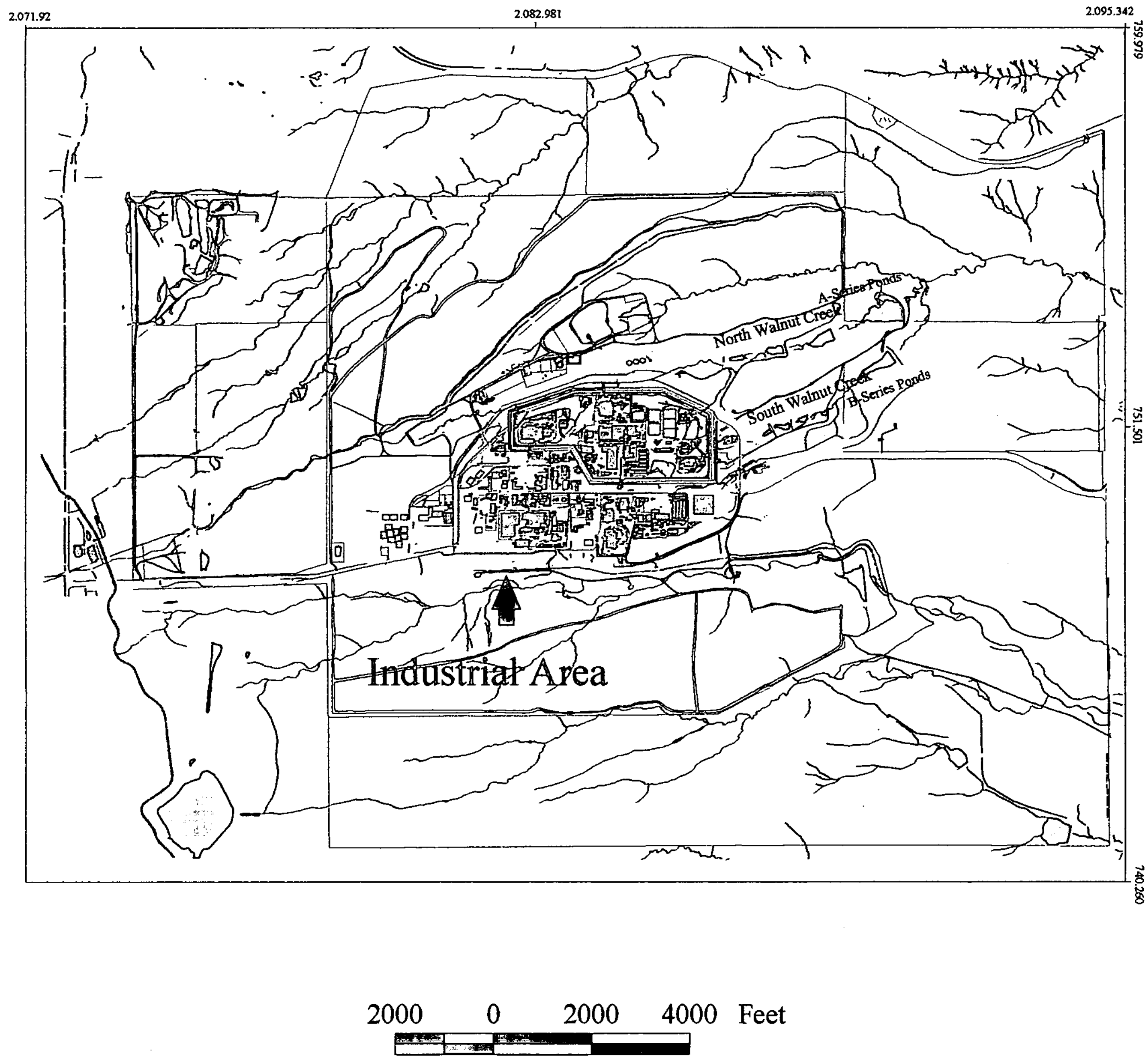
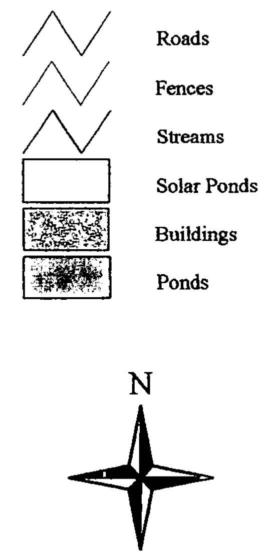


Figure 1

Rocky Flats Environmental Technology Site

Explanation



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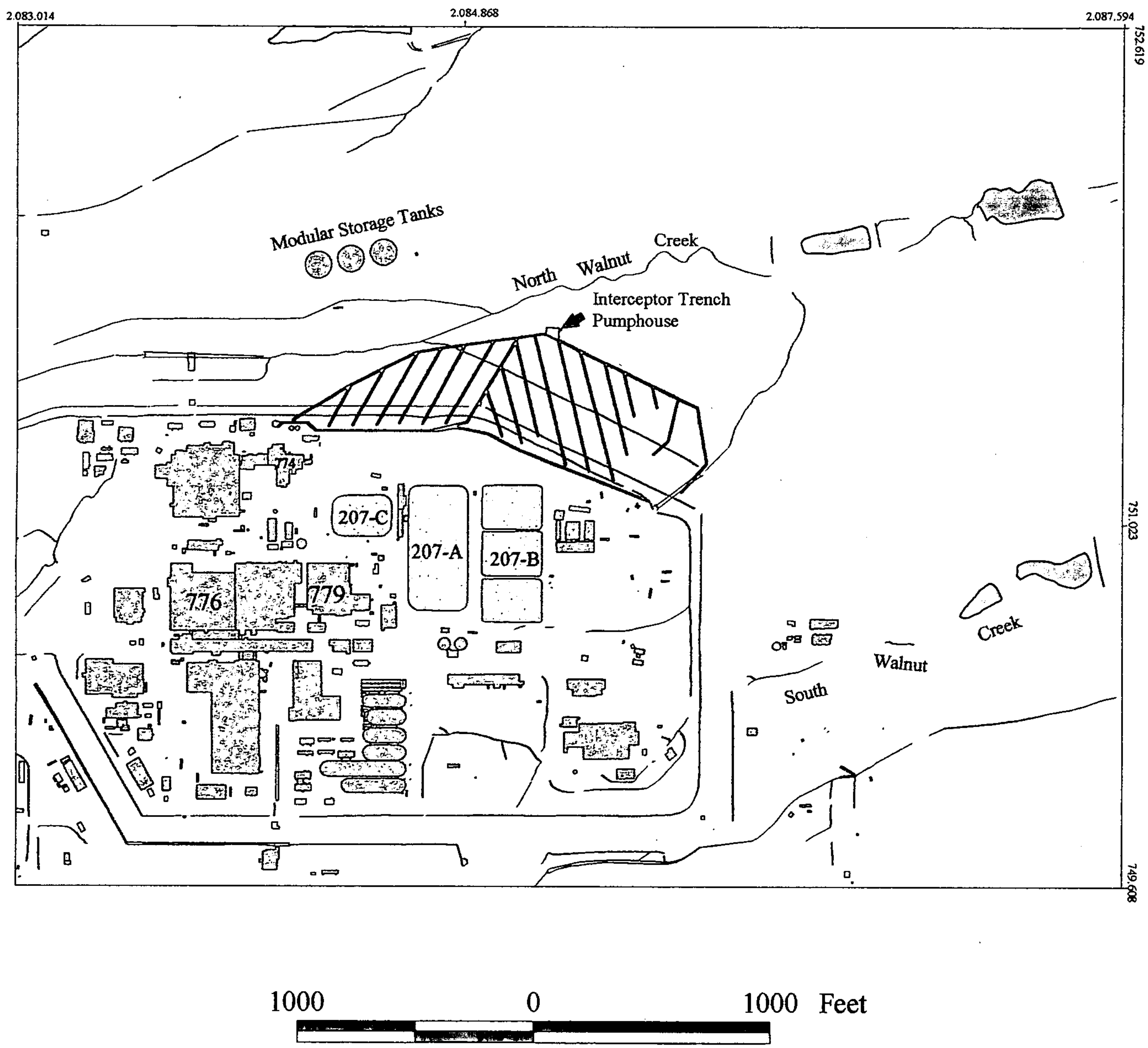

Figure 2

Solar Evaporation Ponds

Rocky Flats Environmental Technology Site

Explanation

- Streams
- Interceptor Trench System (ITS)
- Solar Ponds
- Buildings
- Lakes

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SEP 207-C, but was removed in December 1970. Two additional evaporation ponds (Pond 2 auxiliary and Pond 2D) installed during the 1950's were also removed prior to 1970. Pond 2 auxiliary was in the present day location of Building 779, while Pond 2D was at the current location of SEP 207-C (Figure 3).

The original evaporation ponds were lined with bentonite when constructed, but in the spring of 1954, nitrate-contaminated groundwater was found discharging from springs on the hillside north of the ponds. The cause of this contaminated groundwater was attributed to leakage through the bottom of the ponds (EG&G, 1994). This prompted the construction of SEP 207-A in 1955 and the SEP 207-B series in 1960. SEP 207-A was relined with two 1.5-inch thick layers of asphaltic concrete in 1963. In 1970, SEP 207-C replaced the two remaining evaporation ponds from the original Pond 2 series.

During their period of operation, the ponds received liquid wastes including low-level radioactive process wastes containing high nitrate concentrations, neutralized acidic wastes containing aluminum hydroxide, and additional wastes containing sanitary sewage sludge, lithium metal, sodium nitrate, ferric chloride, lithium chloride, sulfuric acid, ammonium persulfates, hydrochloric and nitric acids, hexavalent chromium, and cyanide solutions. No solvents or other organics were reported to be routinely discharged to the SEPs (DOE, 1995). The SEPs were drained and sludge materials were removed between 1989 and 1995.

1.2 Interceptor Trench System (ITS)

Between 1971 and 1974, a series of six trenches and two sumps were installed in the unconsolidated alluvium between the SEPs and North Walnut Creek to remove groundwater. The exact configuration of these trenches is unclear, but it was reported that they successfully reduced nitrate levels in North Walnut Creek (EG&G, 1994). The early system was taken out of service in 1981 and the Interceptor Trench System (ITS) was put in place in order to remove excess groundwater from the hillslope.

The current ITS is a series of french drains that lie directly to the north of the SEPs, on the hillslope between the SEPs and North Walnut Creek (Figure 2). Water collected by the drains is directed through pipelines to the interceptor trench pumphouse (ITPH) sump, which is located near the base of the slope extending from the SEPs to North Walnut Creek. From the ITPH sump, the collected water is transferred to a set of three 500,000-gallon modular storage tanks (MSTs) located on the hillslope immediately north of North Walnut Creek. Water from the MSTs is currently treated in the Building 374 evaporator system.

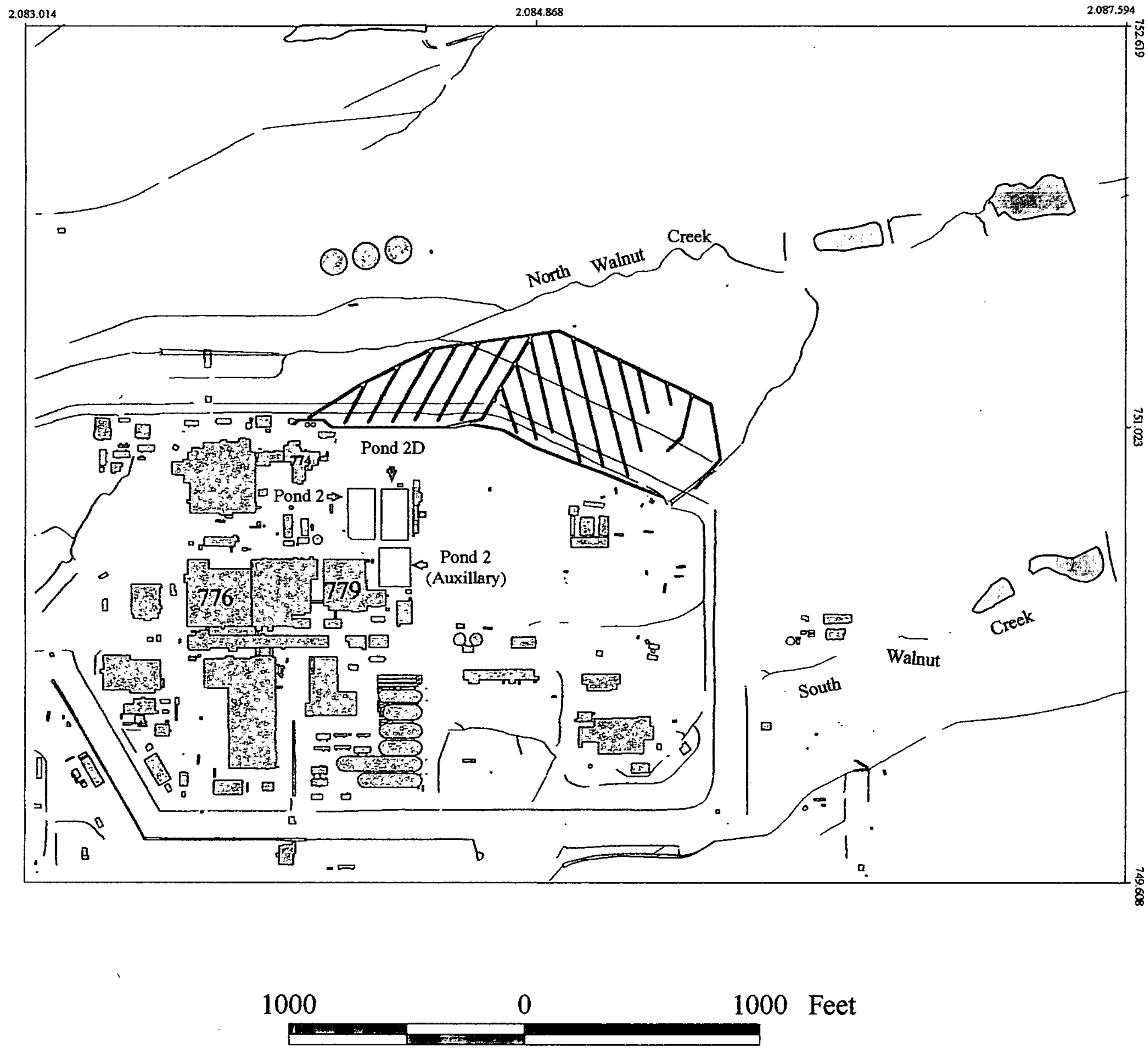

Figure 3

Historical Solar Ponds

Rocky Flats Environmental Technology Stite

Explanation

Streams

Interceptor Trench System (ITS)

Buildings

Lakes

Historical Solar Ponds

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A southern extension of the ITS was constructed in 1982 and can be seen on Figure 2 as the southernmost drain of the ITS, paralleling the perimeter of the IA. The southern extension was constructed to intercept surface water flows from groundwater seeps immediately north of the SEPs that were thought to be contributing to elevated levels of nitrate contamination in North Walnut Creek (EG&G, 1994).

2 GEOLOGIC SETTING

2.1 Regional

RFETS is located approximately 4 miles east of the Front Range section of the Southern Rocky Mountain province, along the western margin of the Colorado Piedmont section of the Great Plains Physiographic Province (Spencer, 1961). The IA of RFETS is situated on an alluvial covered pediment, with the upper surface of the alluvium sloping 1 to 2 degrees in an easterly direction. Several ephemeral streams, generally flowing towards the northeast, dissect the area (Figure 1). The regional flow of groundwater is reportedly controlled by the slight easterly dip in the bedrock (EG&G, 1995b).

2.1.1 Alluvium and Soil

The surficial unconsolidated unit at RFETS consists of the Rocky Flats Alluvium, colluvium, and valley-fill alluvium. The Rocky Flats Alluvium is a Quaternary age alluvial-fan deposit that is heterogeneous, but is dominantly composed of angular to subrounded, poorly-sorted, coarse, bouldery-gravel with a clay and sand matrix. The unit ranges from a thickness of about 100 feet at its western edge, to less than 1 foot at its eastern edge. Beneath the central portion of RFETS, it is approximately 15 to 25 feet thick.

The colluvium and valley fill alluvium are younger deposits and are derived from the Arapahoe and Laramie formations (discussed below) as well as older alluvial deposits. They commonly flank the Rocky Flats Alluvium, occurring on the slopes along the principal drainages.

2.1.2 Bedrock

The Cretaceous bedrock units present near the surface at RFETS are sedimentary in origin and include, in order of increasing age and depth, the Arapahoe and Laramie formations, the Fox Hills Sandstone, and the Pierre Shale. The bedrock formations have a regional dip of approximately 2 degrees to the east, and the subcropping strata become progressively older to the west.

The Arapahoe Formation extends from a depth of about 15 to 40 feet over much of RFETS, and is composed of siltstones, claystones, and lenticular sandstone lenses. The Laramie Formation, which extends from a depth of about 40 to 750 feet beneath RFETS, is also composed of siltstones, claystones, and lenticular sandstone lenses, with a lower coal interval. In portions of RFETS where the Arapahoe Formation is absent, the Laramie Formation subcrops beneath the alluvium.

The upper layers of the Arapahoe and Laramie bedrock formations are frequently weathered, with fractures visible in rock cores collected at RFETS. The thickness of the weathered portion of bedrock varies, commonly being less than 15 feet, but extending up to 60 feet below the top of the bedrock (EG&G, 1995b). Permeability within the weathered portion of the bedrock is approximately two orders of magnitude greater than that of the unweathered zone. Fracturing observed in the bedrock core samples tends to be discontinuous, sub-horizontal to sub-vertical and closed with depth (RMRS, 1996b).

The Fox Hills Sandstone, along with the permeable lower sandstones and coals of the Laramie, constitutes a regional aquifer system. This aquifer outcrops only along a narrow north-south trending pattern on the western edge of RFETS, upgradient from any known sources of contamination. Beneath the site, where the Fox Hills Sandstone is located between about 750 and 850 feet below ground surface, the low vertical hydraulic conductivity (5.8×10^{-8} cm/sec) of the unweathered portion of the Laramie Formation is thought to provide an effective barrier to the downward migration of contaminants from RFETS to the aquifer, barring the presence of preferential flow paths through interconnected fractures or faults. (RMRS, 1996b; EG&G, 1995b).

The Pierre Shale, which underlies the Fox Hills Sandstone, outcrops only at the extreme western edge of RFETS, has no influence on the SPP, and is not an important part of the conceptual model for the SPP.

2.2 Solar Evaporation Ponds Area

The subsurface in the vicinity of the SEPs reflects the regional geology, with a thin layer of alluvial deposits overlying the bedrock. These units are discussed further in the following sections.

2.2.1 Alluvium and Soil

The unconsolidated material directly beneath the SEPs has a thickness of approximately 10 feet. In the area surrounding the SEPs, this thickness varies from slightly less than 5 feet in isolated spots to approximately 20 feet. The variation is largely a result of the underlying bedrock topography. The upper surface of the bedrock in the vicinity of the SPP has been characterized by lithologic data derived from monitoring wells, piezometers, and soil borings (ERM, 1996). Figure 4 is a cross-section which combines historical geologic data and surface and subsurface geophysical measurements, and distinguishes between lithofacies (sandy, sandy gravel, clayey silty gravel, clayey & silty, artificial fill or colluvium) of the unconsolidated surficial materials and the bedrock (claystone, siltstone, sandstone) (DOE, 1995). The cross-section location is shown on Figure 5.

The geometric means of hydraulic conductivity values measured for samples of Rocky Flats Alluvium, colluvium, and valley-fill alluvium are 2.06×10^{-4}, 1.15×10^{-4}, and 2.16×10^{-3} cm/sec, respectively (RMRS, 1996b). Based on laboratory measurements, the porosity of the alluvium is approximately 36 percent (DOE, 1995).

Several references document the use of artificial fill north of the SEPs. Core samples of alluvium collected near the ITS contained fragments of claystone bedrock and plant roots intermixed with alluvial materials at depths up to 14 feet below the surface. These samples may represent either landslide colluvium or fill used during the installation of the ITS (DOE, 1995).

2.2.2 Bedrock

The upper surface of the bedrock pediment beneath and in the vicinity of the SEPs is irregular, both in topography and in subcropping lithofacies. Beneath SEP 207-C and a small portion of SEP 207-A, a sandstone of the Arapahoe Formation is in contact with the overlying unconsolidated material (DOE, 1995). Although no groundwater samples were collected from directly beneath the SEPs, samples collected within the weathered bedrock 50 to 200 feet north of the SEPs show elevated concentrations of nitrate. This zone of hydraulic connection between the alluvium and permeable bedrock provides a possible avenue by which contaminated water from the SEPs may have entered the upper weathered portion of the bedrock (DOE, 1995). Also, isolated sandstone lenses subcrop between the SEPs and North Walnut Creek and are hydraulically connected to the overlying unconsolidated material. Such heterogeneities in the bedrock may have some local influence on the movement of the contaminant plumes (ERM, 1996).

The geometric means of hydraulic conductivity values for the weathered claystone, siltstone, Arapahoe Formation sandstone, and Laramie Formation sandstone are 8.82×10^{-7}, 2.88×10^{-5}, 7.88×10^{-4}, and 3.89×10^{-5} cm/sec, respectively (RMRS, 1996b). Bulk porosity of the fractured bedrock is approximately 38 percent (DOE, 1995). The effective porosity controlling groundwater movement (*ie.* secondary porosity) of the fractured bedrock is likely to be considerably lower than the reported bulk porosity value. Literature sources report effective porosity values for fractured claystone ranging from less than 1 percent to greater than 5 percent, with a typical value of approximately 1 percent (Domenico and Schwartz, 1990).

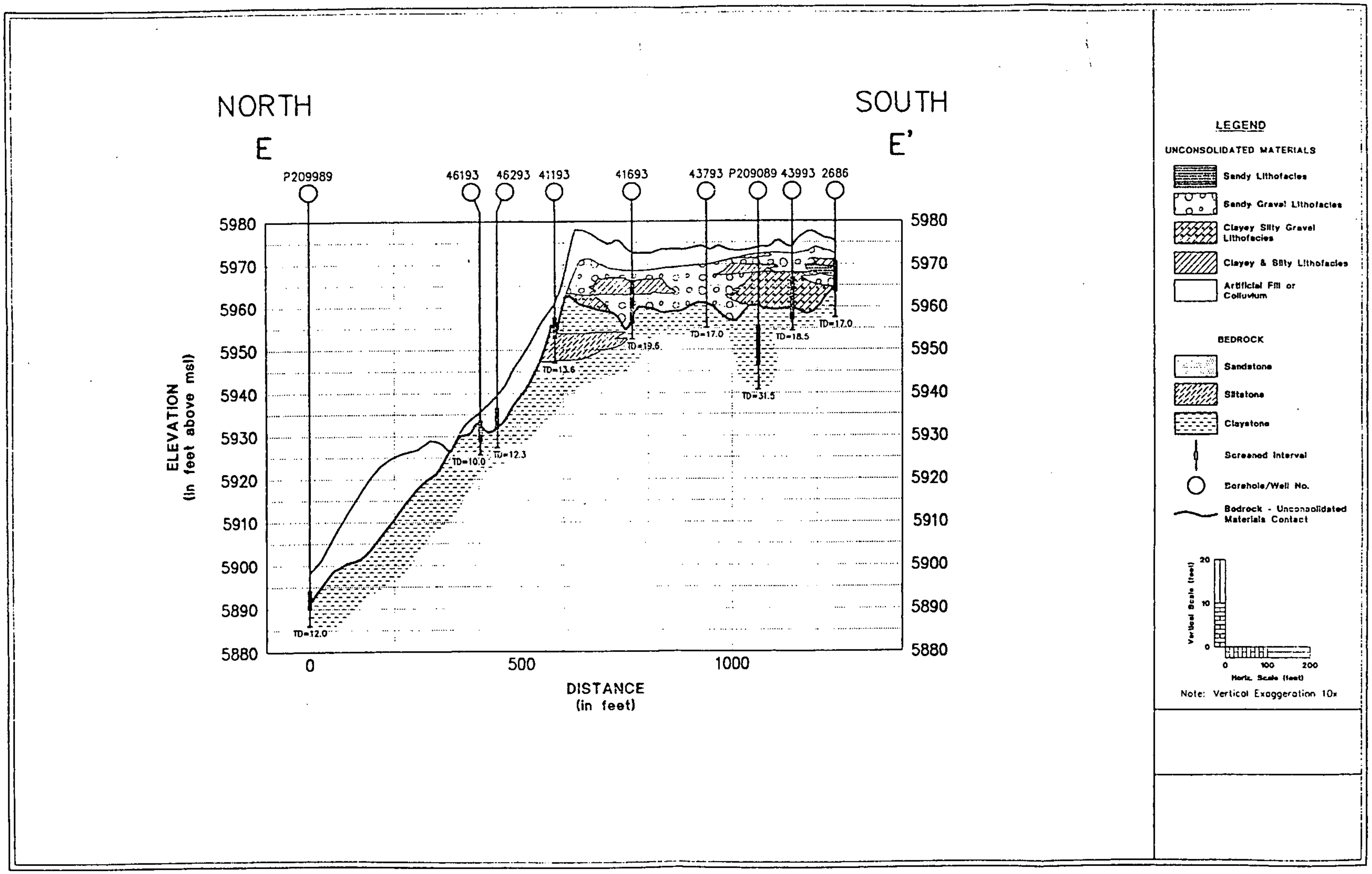

Figure 4 - Geologic cross-section E-E' (from DOE, 1995).

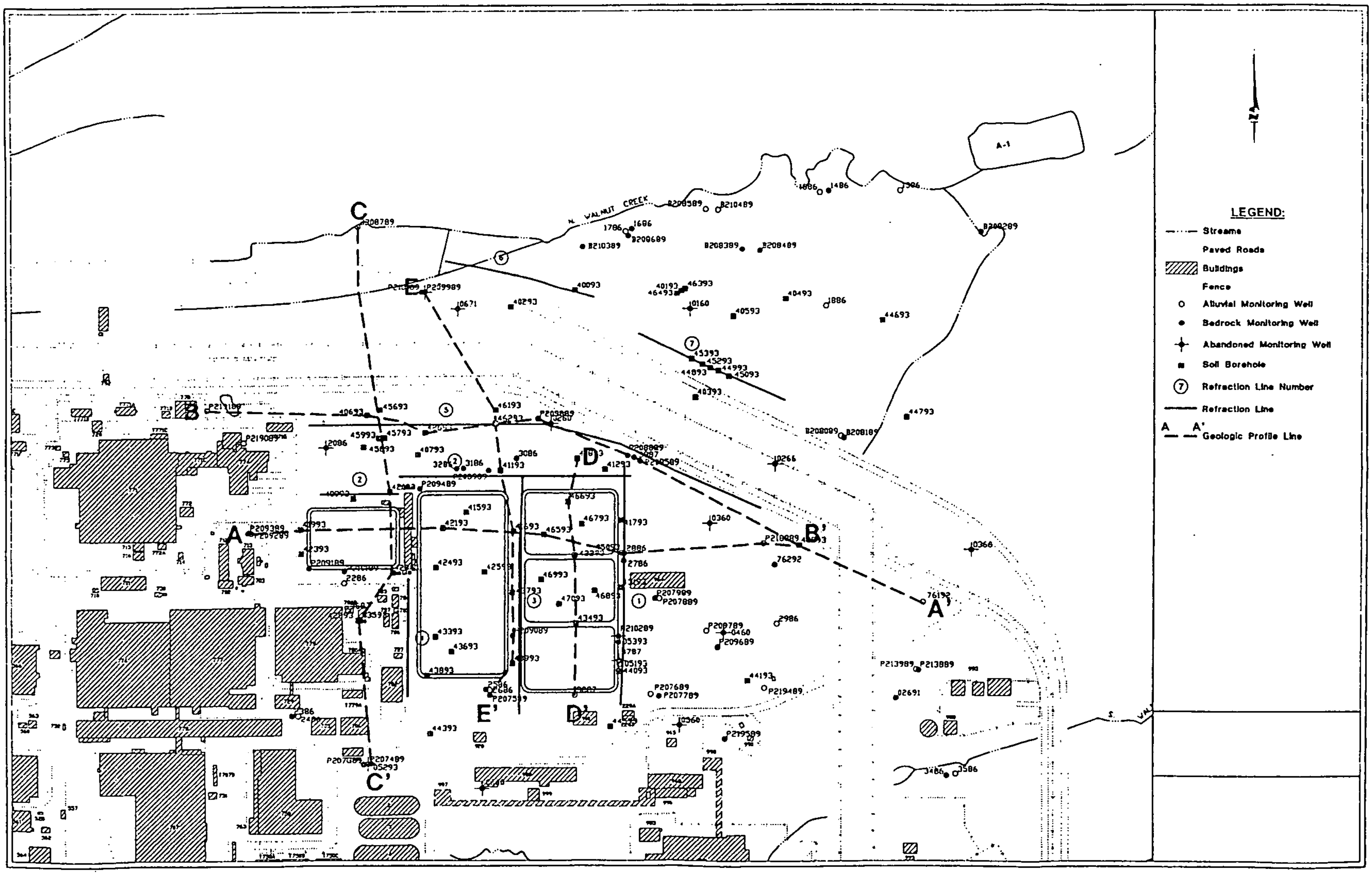

Figure 5 - Location of geologic cross-section E-E' (from DOE, 1995).

2.2.3 Possible Presence of Faults and/or Fractures at Depth

The presence of several shallow bedrock faults have been inferred at RFETS based on correlation of borehole lithology and downhole geophysical data (EG&G, 1995a). One of several faults detected at the site is a north-trending reverse fault that runs beneath SEP 207-B, and continues north through Walnut Creek, joining a north-east trending fault approximately 1 mile north of the SEPs. Based on lithological correlation, the displacement along this fault varies from 50 feet at the south end to 90 feet at the north end (EG&G, 1995a, 1995b).

Hydrogeologic testing and inspection of bedrock cores taken beneath and in the vicinity of the SEPs have confirmed that fractures exist within the shallow bedrock in this area. Field measurements have also indicated that the hydraulic conductivity of the weathered portion of the bedrock is approximately two orders of magnitude greater than that of the underlying unweathered bedrock (ERM, 1996).

Fractures observed in the unweathered bedrock are generally sub-horizontal, and the potential for vertical migration of contaminants through the unweathered bedrock is considered low (RMRS, 1996b).

3 HYDROLOGY

3.1 Climate

The RFETS site is located in a semiarid climate with wide daily and seasonal temperature ranges. The monthly average of daily high temperatures at the site ranges from a maximum average daily high of 82° Fahrenheit (F) in July, to a minimum average daily high of 41° F in January (EG&G, 1995b).

3.1.1 Precipitation

The average annual precipitation, measured over the time period 1961-1990 is 15.69 inches, with the maximum annual precipitation being 25.67 inches, recorded in 1969 (EG&G, 1993a). Of the average annual precipitation, 36 percent or 5.6 inches is snowfall (EG&G 1995b), and 30 percent or 4.7 inches falls during summer thunderstorm events (RMRS, 1996a). The remainder falls during light rain events in the summer and early fall. A breakdown of the mean monthly precipitation for the period 1961 to 1990 is given in Table 1.

Table 1 - Normal monthly precipitation (1961 – 1990) at the Rocky Flats Environmental Technology Site.

Month	Mean Precipitation (inches)
January	0.46
February	0.53
March	1.24
April	1.75
May	2.74
June	2.05
July	1.64
August	1.57
September	1.46
October	0.91
November	0.80
December	0.54
TOTAL	15.69
Source: (EG&G, 1993a).	

3.1.2 Evapotranspiration

The mean annual wind speed was 9 miles per hour in 1993, with slightly windier conditions prevailing during the winter months. The mean relative humidity in 1993 was 41 percent, with the long-term average being 46 percent (EG&G, 1995b). Given the high air temperatures discussed in Section 3.1 and the low relative humidity, the potential for evapotranspiration of water in the shallow groundwater zone is high at the site. A computed estimate of the potential rate of evapotranspiration is reported as 39 inches/year (Fedors and Warner, 1993), with the rate being lower in the winter than in the summer.

A one-year evapotranspiration study conducted at a similar site near Golden, Colorado (EG&G, 1993b) showed that large quantities of water appeared to infiltrate the soil surface, but generally did not progress beyond the effective extraction depth of the native vegetation root system, estimated to be about 7 feet. During exceptionally wet months in the spring, infiltration beyond this 7 foot depth was observed at the Golden site.

3.1.3 Surface Water

Surface water flow at RFETS is generally to the east-northeast within several ephemeral streams, which may be gaining or losing streams in different reaches along their length. The main creeks in the immediate vicinity of the SPP are North and South Walnut Creek, which, along with No Name Gulch, join to form Walnut Creek to the northeast of the SPP.

North Walnut Creek is located approximately 1,000 feet north of, and approximately 110 feet lower than, the SEPs, at an elevation of approximately 5,860 feet above mean sea level. A relatively uniform 1:10 slope extends from the ponds northward to North Walnut Creek. The surface topography to the north of North Walnut Creek is a reflection of the topography between the SEPs and the creek, rising relatively steeply to the north. North Walnut Creek contains four managed water storage areas, referred to as the A-Series Ponds (Figure 1). Water levels and discharges from each pond in the series are fully controlled to ensure that water leaving RFETS meets applicable standards and is in compliance with environmental regulations. South Walnut Creek begins approximately 1,000 feet southeast of the SEPs, and also has a similar series of managed water storage areas, called the B-Series Ponds (Figure 1).

3.2 Groundwater

The SPP groundwater system is largely controlled by surface topography and the configuration of the underlying bedrock surface. Groundwater flows from points of recharge or underflow on topographic highs such as the plateau on which the SEPs are located, and discharges to the streams and topographic lows, such as North and South Walnut Creek. Groundwater also discharges to the ITS installed in the hillslope between the SEPs and North Walnut Creek.

3.2.1 Water Sources

Recharge and subsurface inflow to the groundwater system at RFETS originates from both natural and anthropogenic sources. These sources include recharge from natural precipitation and plant operations, as well as subsurface inflows across the site boundaries as described below.

Natural Subsurface Inflow

Natural groundwater inflow from precipitation recharge and other sources west of RFETS enter the site area along the western boundary, and flow eastward beneath the plant property. A portion of this groundwater underflow contributes to groundwater flow within the SPP.

Infiltration

Historical fluctuations in the position of the water table of up to 9 feet have been observed in the immediate vicinity of the SEPs, with the time lag between a major precipitation event and the corresponding rise in the water table being on the order of days (DOE, 1995). Based on hydrographs from observation wells for the spring of 1992, and specific yield information from pumping tests, calculated recharge rates ranged from 1.6 to 2.2 inches/year (RMRS, 1996c).

A separate evaluation of groundwater recharge through the various material types present in the alluvium was performed during calibration of a site-wide groundwater modeling effort (RMRS, 1996a). Although the model was not completely calibrated at the time of the report, the values of recharge used were in agreement with the hydrograph data mentioned above. The values used in the model ranged from 0.4 to 2.2 inches/year for the various types of unconsolidated materials at the site.

In the SPP area, estimates of the maximum percolation rates by interstitial flow through the vadose zone soils are too low to account for the rapid rise of the water table following a precipitation event. A more direct means of groundwater recharge is thought to exist in the form of vertically-oriented macropores and root holes, or localized zones of higher vertical conductivity, either naturally occurring or in areas where artificial fill was used (DOE, 1995).

Upgradient Plant Processes

Prior to 1994, the surface runoff from the area surrounding Building 779, located southeast of the SEPs, was collected and diverted via a 15 inch diameter corrugated metal pipe to the hillslope immediately north of the SEPs. This storm-water release system was designed such that any water released was captured by the ITS. It was estimated that prior to 1994, up to 36 percent of water entering the ITS was stormwater runoff from the Building 779 area (EG&G, 1995b).

3.2.2 Discharge and Extraction

Groundwater discharges to both surface water bodies and a variety of subterranean drains installed at RFETS. These discharge points are discussed in the following sections.

Subterranean Piping Systems

Within the IA at RFETS, a variety of subterranean piping systems exist that can recharge or dewater the groundwater system. A mass balance of flux to and from the groundwater system from four types of subterranean piping systems was performed for the IA as a whole (RMRS, 1996d). The piping systems considered, and the volume of water they exchange with the groundwater system, are shown in Table 2.

Table 2 - Flux to groundwater from subterranean piping systems.

System	Flux to GW	Flux to Piping System	Net Flux to GW
Sanitary Sewer	2.46	4.42	-1.96
Storm Sewer	10.23	26.2	-15.97
Loss From Water Supply System	12.99	N/A	12.99
Foundation Drain Discharge	N/A	2.14	-2.14
Total Flux to GW			-7.08
(Fluxes are provided in millions of gallons/year) Source: (RMRS, 1996d)			

It is not possible to calculate the spatial distribution of this loss of water from the groundwater system, but an areal average for the entire IA may be calculated. Based on an area of 400 acres for the IA, the loss of groundwater to the various piping systems is 0.65 inches/unit area/year (RMRS, 1996d).

Streams and Seeps

Data from a spring and seep study conducted in 1995 (RMRS, 1996e) indicated that seeps typically occur where the contact between the Rocky Flats Alluvium and the underlying bedrock has been exposed by downcutting in stream drainages (EG&G, 1995a). Seeps could also exist where sandstone lenses in the Arapahoe Formation subcrop beneath colluvial materials on a hillside. Several seeps have been observed on the hillslope immediately to the north of the SEPs (EG&G, 1994).

Interceptor Trench System

The ITS consists of a series of french drains, installed in the hillslope north of the SEPs (Figure 2). It is designed to capture groundwater and surface water flow, with some redundancy built into the configuration of the trenches so that groundwater intercepts at least three separate trenches along a flow path to North Walnut Creek. Each drain consists of a trench, typically between 4 and 15 feet deep by 1 foot wide, backfilled with gravel, and a 4-inch PVC drainpipe located approximately 2 inches above the bottom of the trench. The maximum water storage volume of the trenches is 20,000 gallons, assuming a porosity of 35 percent for the gravel backfill (EG&G, 1994). The maximum rate at which water can be transferred from the ITPH to the MSTs has been estimated at 100 gallons per minute (EG&G, 1993a).

Infiltration of water into the ITS following a precipitation event is rapid, as evidenced by the high degree of correlation between daily discharge volumes for North Walnut Creek and the ITS Central Sump (RMRS, 1996f). Runoff hydrographs constructed using a mathematical model show that, for storm events greater than 0.5 inches/2 hours, the surface runoff flow rate is greater than the maximum capacity (100 gpm) of the ITPH (EG&G, 1993a). For such storms, once the storage capacity of the trenches (20,000 gallons) is exhausted, the surface runoff bypasses the ITS.

Estimates of the volume of groundwater being captured by the ITS range from 1,051,000 (EG&G, 1993a) to 1,787,000 gallons per year (RMRS, 1996g). The lower of the two flux estimates was calculated using a mathematical model based on Darcy's Law and observed site conditions. The higher flux estimate was a measurement of actual discharge from the ITS during a six-month period (May to November 1993) in which there was no precipitation. This suggests that the mathematical model may underestimate the volume of groundwater captured by the ITS. The overall discharge rate of water from the ITS, including both the groundwater discharge discussed above, as well as surface water, has been measured to be about 3 million gallons/year (RMRS, 1997a; RMRS, 1996f). The volume of water captured by the ITS is highest during the spring months, coincident with the period of greatest snowmelt.

The ITS has been observed to dewater the alluvial sediments surrounding the trench system (ERM, 1996). Groundwater elevations recorded in May and September 1994 indicated a water table surface on the majority of the hillslope north of the SEPs that coincided with the top of the bedrock surface, which is also the approximate base of the ITS (ERM, 1996). The size of the zone of dewatered alluvium varied seasonally, with water levels generally being higher in the late spring and early summer, after the snowmelt and higher precipitation of the spring months. In general, the dewatered zone corresponds fairly closely with the zone in which the ITS is keyed into the bedrock (EG&G, 1994).

The ITS was designed to intercept groundwater and surface water flow from a zone approximately 1,760 feet in length. However, the ITS does not completely capture groundwater flow through the alluvium along its entire length. Sections of the ITS, including the easternmost 230 feet of the french drain system, do not extend into the bedrock. Consequently, some groundwater flows below the ITS in these areas (EG&G, 1994). The portion of the ITS that is keyed into bedrock is shown in Figure 6. In addition, the ITS reportedly does not capture groundwater flow in the upper weathered portion of the bedrock beneath the alluvial materials (EG&G, 1994).

3.2.3 Groundwater Levels

Two sets of groundwater elevations were collected in the SPP area in September 1994 and May/June 1995 (ERM, 1996). In addition, a set of groundwater levels are currently being collected, and these data will, to the extent possible, be used in the analysis of remedial alternatives for the SPP. The available data show that the groundwater flow path diverges beneath the SEPs, following the hillslopes north-northeast towards North Walnut Creek, and southeast towards South Walnut Creek. The water levels within the unconsolidated deposits mimic the surface topography, and exhibit seasonal variations in saturated thickness (ERM, 1996).

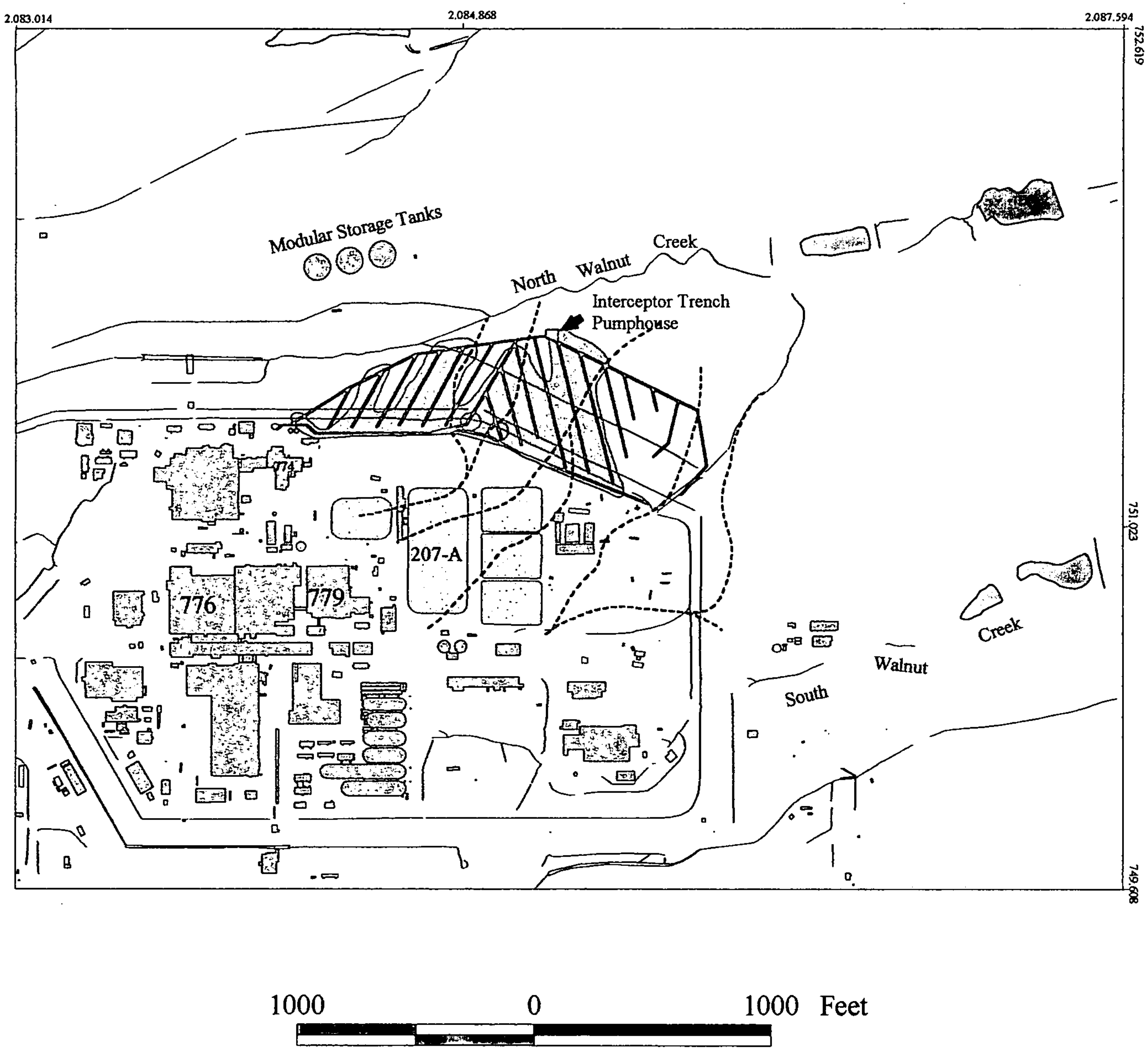

Figure 6

Portion of ITS That is
Keyed Into Bedrock
and Location of Suspected
Paleochannels on Bedrock Surface

Rocky Flats Environmental
Technology Site

Explanation

- Paleochannels
- Streams
- Interceptor Trench System (ITS)
- ITS Keyed to Bedrock
- Solar Ponds
- Buildings
- Lakes

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Princeton, NJ

The vertical hydraulic gradients based on the measured water elevations (ERM, 1996) show downward gradients between the unconsolidated deposits and the weathered bedrock near the SEPs, and upward gradients near North Walnut Creek. Horizontal hydraulic gradients in the unconsolidated deposits indicated by the water level data show lower horizontal gradients (as low as 0.01) near the SEPs, with higher horizontal gradients (up to 0.12) on the hillslope north of the SEPs. Horizontal gradients in the weathered bedrock were similar in magnitude and direction (ERM, 1996).

Measured hydraulic conductivities and representative porosities would result in groundwater velocities in the overburden ranging from 3.2×10^{-6} to 7.2×10^{-4} cm/s, and from 8.8×10^{-7} to 9.5×10^{-3} cm/s in the upper bedrock. Lesser horizontal hydraulic gradients of 0.01 to 0.07 between the SEPs and the headwater area of South Walnut Creek would result in estimated groundwater flow velocities of 3.2×10^{-6} to 4.2×10^{-4} cm/s in the overburden, and from 8.8×10^{-7} to 5.5×10^{-3} cm/s in the upper bedrock.

4 SOLAR PONDS PLUME

4.1 Extent of Groundwater Contamination

The plume of nitrate and uranium contaminated groundwater originating from beneath the SEPs consists of a major zone of contamination located north-northeast from the SEPs in the direction of North Walnut Creek and a smaller lobe of the plume extending a few hundred feet southeast from the SEPs, toward South Walnut Creek (Figure 7). This configuration is the result of groundwater flow following the bedrock topography of the SEP area.

The most complete recent depiction of the extent of nitrate and uranium contamination in groundwater in the vicinity of the SEPs is provided by data from groundwater samples collected in May/June 1995 (ERM, 1996). Further plume characterization studies are currently in progress, and these data will be factored into the analysis of SPP remedial alternatives as they become available.

Several volatile organic compounds (VOCs) (primarily trichloroethylene [TCE]; tetrachloroethylene [PCE]; carbon tetrachloride [CCL_4]; 1,1-dichloroethylene [1,1-DCE]; and chloroform) have been detected in wells located in the area of the western SEPs and to the southeast of the SEPs. It is believed that this VOC contamination originated from source areas to the west and southeast of the SEPs (RMRS, 1997d). Exceedances of the Rocky Flats Cleanup Agreement (RFCA) groundwater standards for several metals (eg. nickel, lithium, cadmium) have also been detected in the vicinity of the SEPs. For the purposes of developing a conceptual model of SEP-related contamination and evaluation of SPP remedial alternatives, this study will focus solely on the distribution of dissolved nitrate and uranium in groundwater.

4.1.1 Nitrate Plume

Background concentrations of nitrate were found to range from 0.52 to 1.14 mg/L for groundwater discharging into streams and seeps, respectively, in areas of RFETS unaffected by the industrial processes at the site (RMRS, 1996f). The nitrate component of the SPP extends approximately 1,300 feet in a north-northeasterly direction along the groundwater flow path from the SEPs to North Walnut Creek. A smaller zone of nitrate-contaminated groundwater also extends in the overburden approximately 1,000 feet in a southeasterly direction from the SEPs towards South Walnut Creek. Based on current data, the

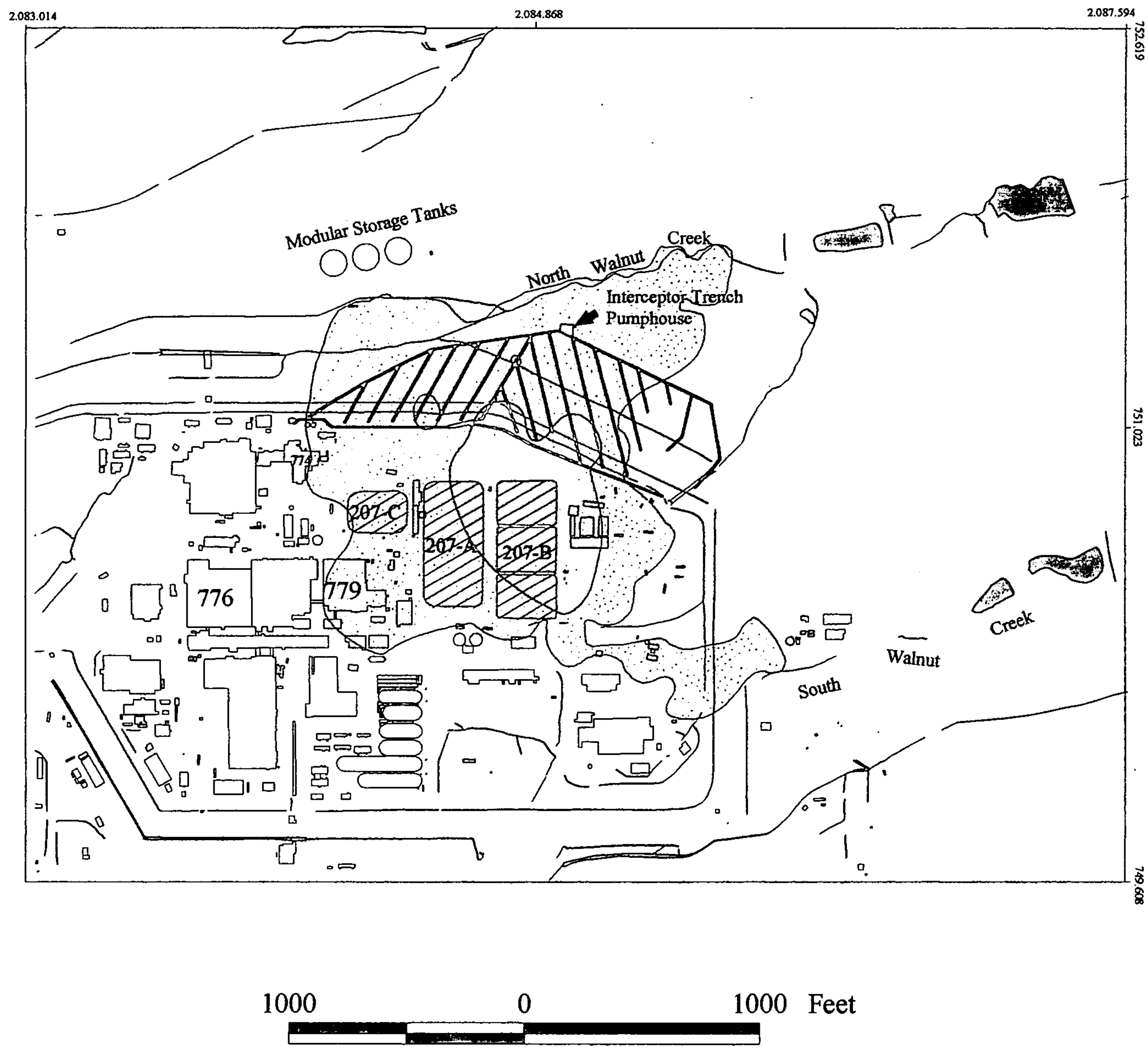

Figure 7

Extent of Nitrate Contamination in Groundwater

Rocky Flats Environmental Technology Site

Explanation

- Streams
- Interceptor Trench System (ITS)
- Solar Ponds
- Buildings
- Lakes
- Nitrate Concentrations Exceeding 1,000 mg/L
- Nitrate Concentrations Exceeding 10 mg/L

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Princeton, NJ

concentrations of nitrate in the southeast lobe of the plume are generally less than 100 mg/L. The concentrations of nitrate in the northern portion of the SPP range from background levels to 4,900 mg/L (ERM, 1996). The highest concentrations were found in the weathered bedrock in a zone extending from immediately north of the SEPs to the ITPH. These concentrations were attributed to the downward hydraulic gradient that exists between the unconsolidated materials and the weathered bedrock (ERM, 1996). Lenses of subcropping sandstone and siltstone are present near the SEPs (Figure 8) which could facilitate the downward movement of contaminants into the bedrock.

The lateral extent of the groundwater plume was greater within the unconsolidated sediments than in the weathered bedrock. The zone in which nitrate levels exceed 10 mg/L is approximately 1,300 feet wide at its maximum width approximately halfway down the slope from the SEPs.

Groundwater samples taken adjacent to North Walnut Creek suggest that nitrate concentrations in groundwater discharging to the creek exceeded 100 mg/L (ERM, 1996). Adjacent to North Walnut Creek, concentrations within the weathered bedrock were generally lower than those within the unconsolidated sediments.

4.1.2 Uranium Plume

The background activity-concentrations for ^{233}U and ^{234}U in groundwater at RFETS vary from non-detect to 200 pCi/L, and from non-detect to 136 pCi/L for ^{238}U (EG&G, 1993c). Fewer sampling data are available to characterize the extent of uranium contamination, but the existing data indicate that uranium is present in groundwater samples collected in the area from the SEPs to North Walnut Creek (ERM, 1996; RMRS, 1997a). It has been noted that the lateral and vertical extent of the uranium plume is generally less than that of the nitrate plume in both the unconsolidated deposits and in the weathered bedrock (ERM, 1996).

The spatial distribution of the groundwater samples analyzed for uranium was not sufficient to produce a contoured diagram of uranium contamination (ERM, 1996). The samples that were analyzed indicated concentrations of between 10 and 46 pCi/L for $^{233+234}U$ and ^{238}U, respectively, in the unconsolidated materials adjacent to North Walnut Creek. A single sample from the weathered bedrock, taken from well B208689 adjacent to North Walnut Creek, showed a concentration of 69.0 pCi/L for $^{233+234}U$ and of 42.0 pCi/L for ^{238}U. The uranium-activity concentrations are generally higher in samples taken from the weathered bedrock zone than from the unconsolidated deposits (ERM, 1996),

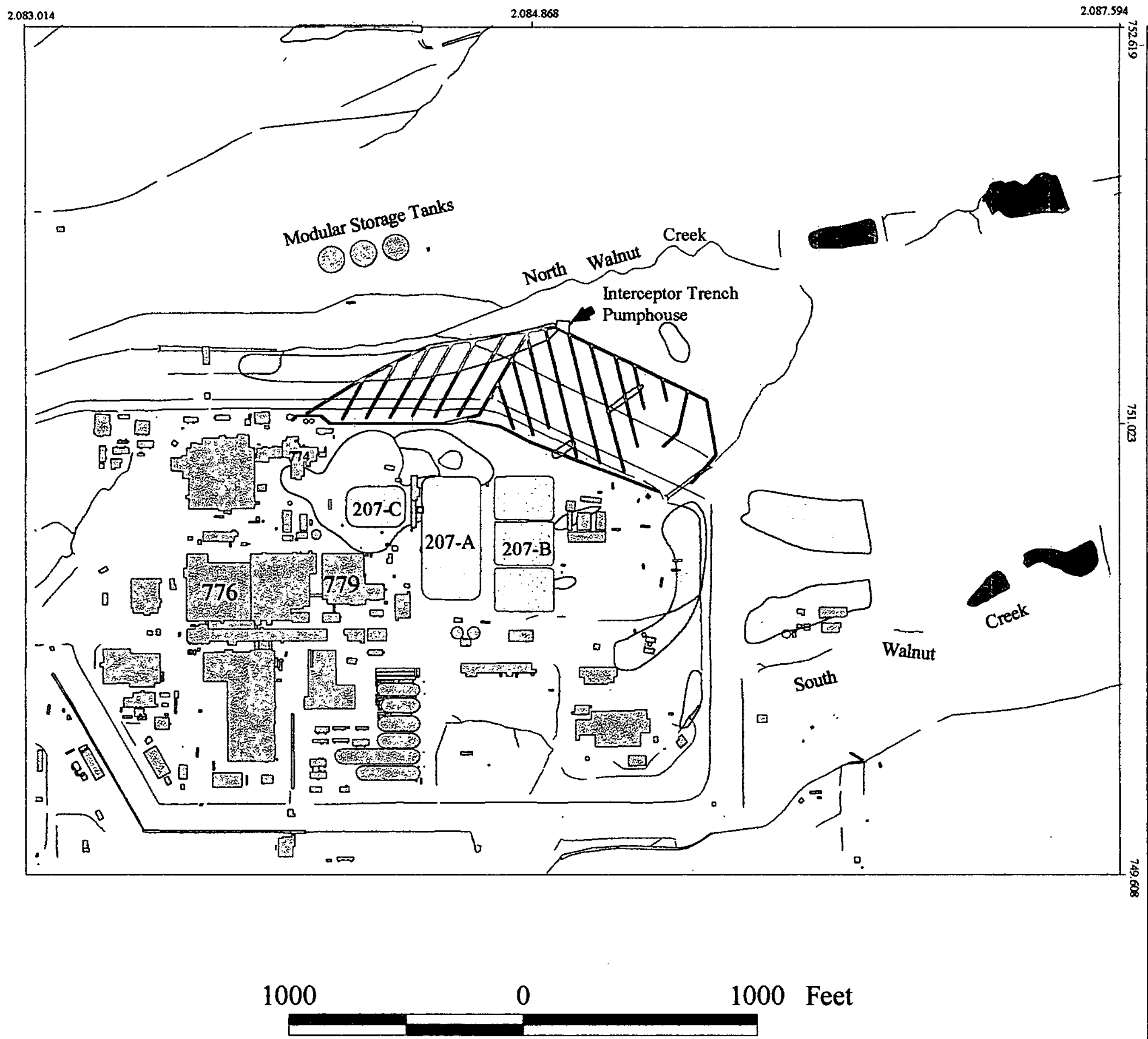

Figure 8

Location of Subcopping Sandstone/Siltstone Lenses

Rocky Flats Environmental Technology Site

Explanation

- Interceptor Trench System (ITS)
- Streams
- Buildings
- Solar Ponds
- Lakes
- Subcropping Sandstone/Siltstone

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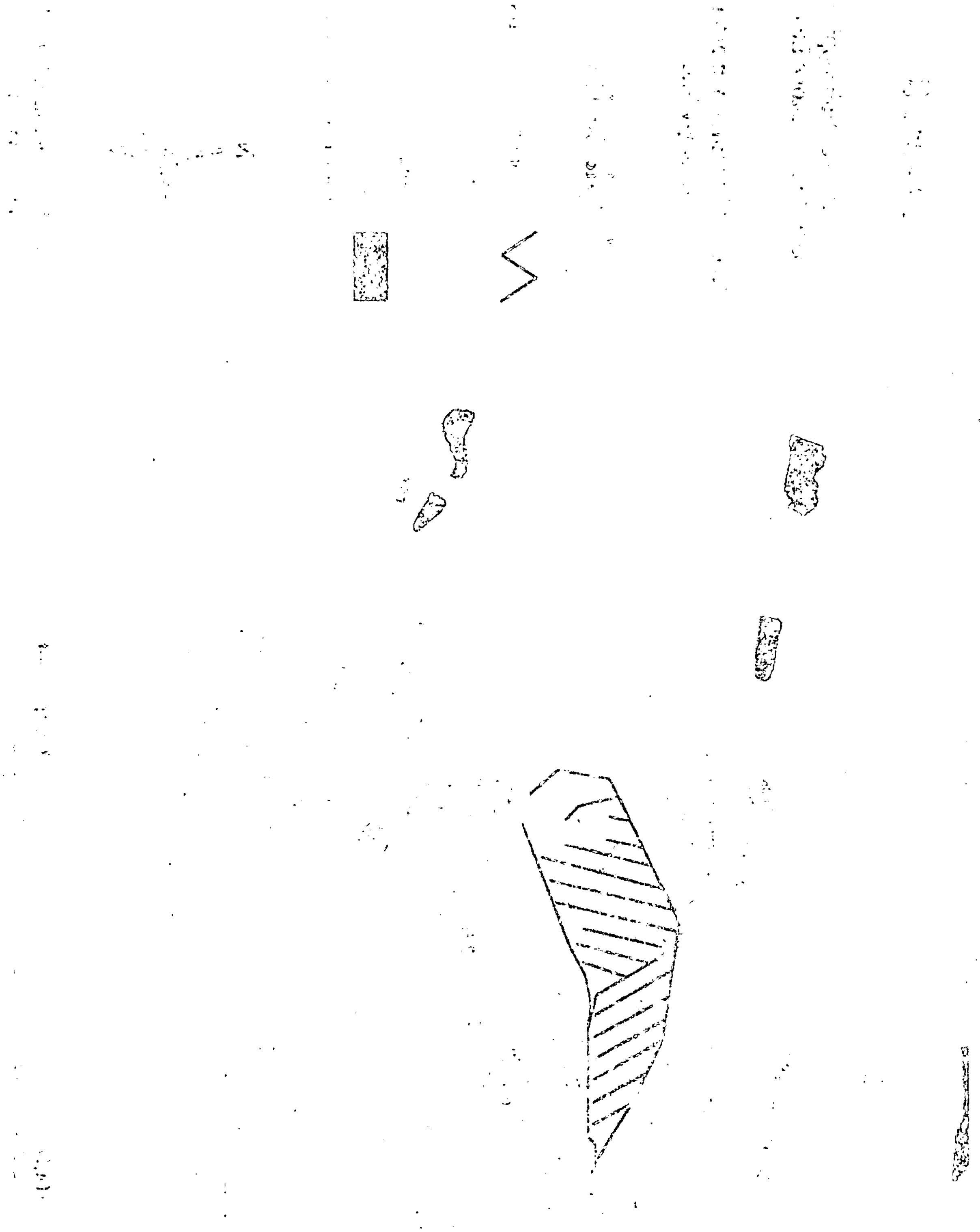
Princeton, NJ



although uranium sampling data for the unconsolidated materials near the SEPs and ITS are sparse. An earlier study (Crawford and Stevanak, 1991) confirmed that total uranium-activity concentrations are higher in the weathered bedrock zone, although their data show peak activity concentrations of over 1,000 pCi/L.

4.2 Sources of Contamination

The SPP extends downgradient from the SEPs in the northeastern portion of the IA. The possible sources of the nitrate and uranium contamination in the SPP are discussed below.

4.2.1 Solar Ponds

Starting shortly after their initial construction in 1953, the SEPs began receiving wastes as detailed in Section 1.1. The presence of nitrates in the soil north and northeast of the SEPs was identified in 1974 from soil analyses and the presence of stressed vegetation on the hillslope. At that time, it was thought that approximately 60 percent of the nitrates were confined to shallow soils within 5 feet below ground surface, and that little, if any, nitrate-contaminated groundwater was entering North Walnut Creek (DOE, 1995). A separate surface water study, also conducted in the early 1970's, reported that nitrate was detected in the A-Series Ponds in the North Walnut Creek drainage (DOE, 1995).

Between the first use of the SEPs in 1953 and the final removal of the residual sludges and liquids from the SEPs in 1995, little information exists regarding the temporal variation in the concentrations of the contaminants in the SEP water. Reports indicate that early pond waters contained greater than of 50,000 mg/L NO_3-N (nitrate reported as nitrogen), which is the equivalent of 221,000 mg/L NO_3 (nitrate reported as nitrate). Sampling of pond waters in 1991 indicated nitrate concentrations less than 2,300 mg/L NO_3-N (DOE, 1995). These concentrations are above the State of Colorado Basic Groundwater Standard Maximum Contaminant Level (MCL) for nitrate of 10 mg/L NO_3-N.

Few data are available regarding concentrations of uranium within the pond water or sludges. The maximum recorded total uranium activity within the SEPs was 48,000 pCi/L in 1991 (RMRS, 1997c).

4.2.2 Other Nitrate and Uranium Sources

The Historical Release Report (DOE, 1992) at RFETS details several contaminant releases upgradient of the SEPs. The french drain immediately to the north of Building 776 was listed as a possible source of radioactive contamination. In addition, a volume of between 50 and 500 gallons of nitrate, plutonium and uranium-contaminated wastewater overflowed from a tank to the east of building 774 in 1981. ^{238}U was also reportedly detected in soil samples in a "bone yard" east of the SEPs that was thought not to be related to disposal in the SEPs (DOE, 1995).

4.3 Controls on Plume Migration

The SPP has been shaped, and will continue to be controlled, by a number of different factors. The overall mass of contamination in the plume was controlled by leaching and infiltration from the contaminant source, and by any degradation or decay processes that might have been occurring within the groundwater system. The contaminant plume has been transported by groundwater flow, with possible interactions between the dissolved contaminants and the rock and soils. The contaminant plume has followed the groundwater flow path, and discharged both to man-made collection systems and surface water bodies.

4.3.1 Leaching/Infiltration from sources

Leakage through the bottom of the SEPs has been the primary avenue for contaminants to enter groundwater in this area (EG&G, 1994). Visual inspection and a geophysical survey of SEP 207-A and 207-B identified cracks and breaches in the liners. Analyses of soil samples taken from beneath the SEPs showed a correlation between contaminant concentrations in the soil, and their location beneath identified breaches (DOE, 1995). Measurements made in piezometers installed adjacent to the SEPs indicated that when the water table is high, the saturated zone reaches 0.7 feet above the base of the southern end of the SEP 207-B South liner (DOE, 1995). Taken together, this evidence suggests that leakage through the base of the SEPs was a likely long-term source of contaminated water entering the groundwater flow system during the approximately 40 years the SEPs were in use (DOE, 1995).

4.3.2 Groundwater Flow

The regional direction of groundwater flow at RFETS is east-northeasterly, as controlled by the eastward dip of the surface topography and bedrock surface. Groundwater flowing to the east-northeast through the IA diverges beneath the SEPs, moving downhill, north towards North Walnut Creek, and southeast towards South Walnut Creek. The overall movement of the groundwater contaminants in this area is controlled by this divergent groundwater flow.

There is a seasonal fluctuation in the hydrogeologic system in the SPP area, with water levels generally being higher in the wetter late spring months due to snowmelt, and lower during the drier fall and early winter months. This fluctuation in the water levels may affect the vertical gradients at the site, which are generally thought to be downwards from the alluvium to the bedrock adjacent to and beneath the SEPs, and upwards along North Walnut Creek (ERM, 1996).

Hydrologic data collected from piezometers near the easternmost portion of the ITS indicate the presence of a paleochannel in the surface of the bedrock, infilled with relatively coarse sediments of high conductivity. Previous investigations suggest that this channel passes underneath the ITS, and represents a possible pathway by which contaminated groundwater may reach North Walnut Creek (EG&G, 1994). The locations of the suspected paleochannels on the bedrock surface are shown in Figure 6.

4.3.3 Dissolved Mass Transport

The chemistry and transport of uranium in the groundwater system is controlled by a number of factors and processes including pH, redox conditions, sorption, and the formation of chemical complexes. Under reducing conditions, uranium will precipitate from solution over the entire natural range of pH, but will remain soluble in an oxidizing environment (Crawford and Stevanak, 1993). Based on the high concentrations of nitrate observed in the SPP, previous investigators have suggested that a lack of organic matter in the soil may have created an oxidizing environment throughout the unconsolidated sediments and weathered bedrock (Crawford and Stevanak, 1993). Such an environment would prevent precipitation of uranium. However, uranium may sorb to other materials, such as clays and iron oxides and hydroxides. Clay is present in both the unconsolidated sediments and in the weathered bedrock, providing a possible sorption substrate that could lead to the retardation of dissolved uranium during transport within the SPP.

Laboratory measurements of uranium sorption to core material retrieved from the SPP area give values of K_d ranging from 31.2 to 171.0 L/kg (Actinide Panel, 1997). The data indicated a trend of decreasing K_d with depth and little correlation with the concentration of nitrate in the water.

For all isotopes of uranium, radioactive decay is not a significant contaminant mass reduction process for the time scales under consideration in this conceptual model.

Nitrate that enters the groundwater system is expected to be mobile, due to its high solubility and low tendency for sorption to solids. Nitrate is stable under oxidizing conditions, with little denitrification or reduction of nitrate occurring. The redox conditions at the site are suspected to be oxidizing (Crawford and

Stevanak, 1993), although the analyses of groundwater samples for the products of denitrification (N_2O and dissolved N_2) have not been carried out (DOE, 1995).

4.3.4 North Walnut Creek and South Walnut Creek

In the natural hydrologic system in the vicinity of the SPP, the North and South Walnut Creek flow channels represent the major discharge points for groundwater that has flowed beneath the SEPs. As such, they are natural points of discharge for the plume of groundwater contamination originating at the SEPs.

The average NO_3-N concentration in mg/L of water in Pond A-3 of the A-Series Ponds between February 1994 and January 1996 was 1.06 mg/L, while the total average uranium activity (sum of ^{233}U, ^{234}U, ^{238}U) between April 1993 and May 1995 was 3.03 pCi/L (RMRS, 1996f). The average NO_3-N concentration in mg/L of water in Pond B-5 of the B-Series Ponds between January 1992 and May 1995 was 2.91 mg/L, while the total uranium activity (sum of ^{233}U; ^{234}U, ^{238}U) between September 1992 and July 1995 was 1.3 pCi/L (RMRS, 1996f).

4.3.5 Interceptor Trench System

The ITS is an engineered system designed to capture the contaminated groundwater plume originating at the SEPs before it reaches North Walnut Creek. As discussed in Section 3.2.2, the ITS captures about 3 million gallons per year of combined groundwater and surface water. Where it is keyed into bedrock, along its westernmost 1,400 feet, it has been demonstrated to effectively capture groundwater flow through the alluvial layer. Along the easternmost 230 feet, where the ITS drains have been placed above the base of the alluvial layer, contaminated groundwater within the alluvial sediments passes beneath the ITS and continues migrating towards North Walnut Creek (EG&G, 1994).

The average NO_3-N concentration in mg/L of water entering the ITS between, based on ten samples collected between November 1993 and September 1995, was 294 mg/L (RMRS, 1996f). The data shows relatively constant nitrate concentrations during this relatively short measurement period. The total uranium activity (sum of ^{233}U, ^{234}U, ^{238}U) in pCi/L of water entering the ITS between 1989 and 1998 is shown in Table 3. The uranium data indicate a trend of decreasing activity-concentrations in the water being captured by the ITS during this period.

Table 3 – Total uranium activity-concentration of water entering the ITS.

Date	Uranium activity-concentration (pCi/L)	Comments
1989	115.76	Average of 3 samples
1990	97.13	Average of 3 samples
10/28/91	84.4	1 sample
06/09/95	24.04	1 sample during a high flow period
Fall 1997 – Spring 1998	68.4	Average of many samples
Source: (Hranac, 1998)		

5 FUTURE CONDITIONS

5.1 Hydrologic System

The hydrologic regime in the SPP area may be affected in the future by natural climatic fluctuations and by changes in the operation of the IA at RFETS. These changes may affect groundwater flow and contaminant migration within the SPP area. Several of the more important anticipated changes in future conditions are discussed below.

5.1.1 Natural

The bi-annual record of precipitation over the past 105 years as measured at the Fort Collins, Colorado weather station indicates relatively low variability. This record, which is thought to be representative of precipitation patterns at RFETS, shows that the total amount of precipitation in two consecutive years was between 22 inches and 40 inches (an average of between 11 inches and 20 inches per year), 90 percent of the time (RMRS, 1996f). However, a multi-year drought or extended period of increased precipitation could affect soil moisture, groundwater levels and flow rates, and the volume of groundwater discharging to surface water bodies or the ITS in the SPP area.

5.1.2 Plant Operations and Closure

The SPP is located on the downgradient perimeter of the IA and the water budget for the area is affected by site operations. Operations within the IA are responsible for both releases and removal of water to and from the groundwater system. The water budget for the IA discussed in Section 3.2.2 showed that industrial processes resulted in a net removal of 7.08 million gallons/year (0.65 inches/unit area/year) from the groundwater system within the IA. This represents a large percentage of the estimated annual recharge at RFETS. If this groundwater removal is reduced or eliminated by the termination of activities within the IA, it will significantly impact the groundwater budget within the SPP.

Placing an impermeable cover over a portion of the IA is also being considered as part of the site closure. This would impact the groundwater system in the form of lost recharge beneath the capped area, although runoff from the impermeable cover could result in additional recharge surrounding the cap.

5.2 Solar Ponds Plume

The evolution of the SPP will be directly tied to changes in the hydrologic system, discussed in the previous section. If the current site conditions are maintained, including operation of the ITS, the SPP is expected to be contained in the alluvium to a significant degree by the ITS but to continue moving towards, and discharging into, North Walnut Creek in the upper weathered bedrock or in zones where the ITS is not keyed to bedrock. More active remediation measures such as those proposed for analysis in the current study, may enhance plume containment and the extent and rate of removal of contaminants.

6 DATA LIMITATIONS

Although an extensive data set has been compiled for development of this conceptual model, there remain some data gaps that may constrain the analysis and evaluation of the remedial alternatives.

6.1 Distribution of Contaminants

The spatial data describing the distribution of contaminants in the groundwater are currently incomplete. Nitrate data have been used to delineate zones in which concentrations exceed 1,000 mg/L and 10 mg/L (the MCL), respectively. The spatial density of groundwater samples analyzed for uranium is not sufficient to produce a similar plot, and the available data do not provide a clear picture of the peak activity concentrations of uranium in the SPP. A thorough understanding of the initial distribution of contaminants is critical to the analysis of remedial alternatives. A groundwater monitoring program conducted from November 1997 to February 1998, as well as monthly monitoring of ITS water for nitrate and uranium may provide a more complete picture of the current contaminant distribution, but these data are not yet available.

Historical data showing the development of the contaminant plume and temporal variations in the composition of the water in the SEPs are limited. In addition, data sets exist describing the long-term temporal variation in the contaminant concentrations in the groundwater at specific monitoring locations are not available. Historical contaminant concentrations over time could provide valuable information for understanding groundwater flow and transport processes within the SPP.

6.2 North Walnut Creek

Water level data north of North Walnut Creek are not available to permit a clear determination of whether there is any flow of groundwater underneath North Walnut Creek. As well, insufficient sampling of groundwater for nitrate contamination has been performed north of North Walnut Creek. The few samples that have been collected indicate concentrations close to background levels within the unconsolidated sediments, and slightly higher concentrations within the weathered bedrock (ERM, 1996). Delineation of the maximum extent of the plume north of North Walnut Creek is not possible with the data currently available. However, the sharp rise in topography of the ground surface and bedrock surface north of North Walnut Creek likely constrain the groundwater plume to the North Walnut Creek drainage.

6.3 Faults and Fractures

Possible faults or deep penetrating fractures within the bedrock are not likely to represent a significant pathway of contaminant migration in the SPP area. The properties of the claystone bedrock itself reduces the probability that faults and associated fractures will be able to transmit contaminants to great depths (RMRS, 1996b). The ductility and moderate swelling of the claystone, combined with the pressure created by the weight of the overlying rock will tend to close horizontal tending fractures and fault zones at depth. Fine-grained sediments derived from weathering of the claystone bedrock may also infill the north-south trending fault that is inferred to exist in the vicinity of the SEPs.

6.4 Potential for Sorption/Biodegradation

The redox conditions at the site are not known, and analyses of groundwater samples for the products of denitrification (N_2O and dissolved N_2) have not been carried out (DOE, 1995). Similarly, the sorption potential for the various uranium isotopes is geochemically complex and poorly understood in the SPP. Tests of site cores to determine the K_d of uranium in the SPP have been conducted, and these data will be considered in the selection of a suitable value for the partitioning coefficient. A search of the scientific literature will be conducted to identify data regarding the potential for denitrification in an environment similar to RFETS.

6.5 Groundwater Recharge

There is uncertainty regarding both the quantity and the physical process of groundwater recharge at the site. Calculations based on water table fluctuations following precipitation events have produced larger estimates of infiltration recharge than those determined from modeling studies. Previous investigators have suggested a process of recharge to the groundwater system that occurs via macropores or larger zones of increased vertical conductivity. Such processes would be difficult to quantify in the field and to represent quantitatively in a model. However, over the time scale that the proposed remedial alternatives are expected to be operational, short term fluctuations in the position of the water table following precipitation events are not likely to significantly affect rates of mass removal, and will not form an important component of the conceptual model. An appropriate rate of recharge will be determined from estimates reported in previous studies and from model calibration during the analysis phase of this study.

6.6 Summary of Data Limitations

In summary, certain data gaps remain in formulating the SPP hydrogeologic system conceptual model. These data gaps will be addressed by obtaining additional data, or by making estimates for parameter values or hydrogeologic conditions to permit the analysis of alternatives to proceed.

The groundwater samples collected in the winter of 1997/98 will be used to refine our understanding of the most current distribution of dissolved nitrate and uranium within the SPP. The basic conceptual model will assume that North Walnut Creek permits no underflow of groundwater. Also, the conceptual model will include no major faults or fracture zones. Fate and transport parameter values for uranium will be obtained from the Actinide Group and the scientific literature, respectively. An appropriate value of infiltration recharge will be determined from previous studies (likely from the lower end of the range), and short term water table fluctuations will not form an important component of the conceptual model of longer-term system response.

The initial values, and range of values determined as part of the conceptual model, will be used as initial values in the planned analysis of alternatives. Due to natural variability and uncertainty in these estimates, it is likely that these values will be adjusted, as appropriate, during the analysis phase. Remaining uncertainty introduced by current data limitations may be addressed in the sensitivity analysis portion of the planned analysis of remedial alternatives.

7 CONCEPTUAL MODEL SUMMARY

Based on information contained in previous sections of this report, a brief summary of the hydrogeologic conceptual model for the SPP is presented here. The SPP is a zone of contaminated groundwater extending downgradient from the SEPs. The discussion in this report focuses on the nitrate and uranium components of the plume.

The SEPs began as the Original Ponds in 1953 and evolved to a configuration of 5 ponds covering approximately 294,000 feet^2 and extending to a depth approximately 5 feet below the elevations of the surrounding berms. The SEPs operated from 1953 through 1993 and received wastes including low-level radioactive process wastes containing high nitrate concentrations, neutralized acidic wastes containing aluminum hydroxide, and additional wastes containing sanitary sewage sludge, lithium metal, sodium nitrate, ferric chloride, lithium chloride, sulfuric acid, ammonium persulfates, hydrochloric and nitric acids, hexavalent chromium, and cyanide solutions. No solvents or other organics were reported to be routinely discharged to the SEPs. The SEPs were drained and sludge materials were removed between 1989 and 1995. This current conceptual model has been developed for the hydrogeologic system surrounding the SEPs and for the nitrate and uranium components of the SPP that will form the focus of the analysis efforts designed to support remedial alternative selection.

The SEPs are located in the northeast corner of the Industrial Area at an approximate elevation of 5,970 feet above mean sea level. A relatively uniform 1:10 slope extends from the ponds northward approximately 1,000 feet to North Walnut Creek, which is located at an elevation of approximately 5,860 feet above mean sea level.

The hillslope aquifer system between the ponds and the creek is comprised of a thin layer of approximately 5 to 20 feet of alluvium overlying a slightly irregular sandstone and claystone bedrock surface. A thin saturated groundwater flow zone has been identified over much of the hillslope, and, prior to installation of the ITS in the lower portion of the hillslope, seeps were observed at several locations on the hillslope. Operation of the ITS has lowered shallow groundwater levels to the elevation of the bedrock surface in the vicinity of much of the trench system.

The uppermost portion of the bedrock is weathered, creating a 15 to 60 feet thick zone of intermediate permeability separating the higher permeability alluvium from the lower permeability underlying bedrock. The upper zone of the competent bedrock is fractured and transmits groundwater flow. Fracture number, spacing, and aperture decrease with depth, and the hillslope aquifer is conceptualized as being essentially impermeable below a depth of approximately 40 to 80 feet.

A portion of the groundwater influx to the SPP area is underflow from the site proper. This water originates from natural underflow to the plant area, natural recharge of water in the plant area itself, and releases of water from various site operations and processes. Surface recharge from precipitation in the vicinity of the SPP has been estimated at 0.4 to 2.2 in/yr.

The majority of groundwater flowing through the hillslope aquifer from the higher elevation area beneath the ponds moves downgradient toward the natural discharge point provided by North Walnut Creek. A localized portion of the groundwater flow extends toward a small swale that forms the headwater area of South Walnut Creek. For the main portion of the saturated zone flowing north to North Walnut Creek, the majority of the flow in the shallow alluvium is captured by the ITS. A portion of the flow near the eastern end of the ITS reportedly bypasses the trench system. The effectiveness of the ITS in capturing groundwater flow in the upper bedrock zone has not been completely determined. The portion of groundwater flow moving toward South Walnut Creek occurs as underflow beneath the headwater swale, and most likely discharges to the creek at some point downgradient.

Hydraulic conductivity of the alluvium material ranges from 1.15×10^{-4} to 2.16×10^{-3} cm/s, while hydraulic conductivity of the fractured upper bedrock zone ranges from 8.8×10^{-7} to 7.88×10^{-4} cm/s. Horizontal hydraulic gradients extending from the SEPs north to North Walnut Creek range from 0.01 to 0.12. Calculated groundwater velocities in the overburden range from 3.2×10^{-6} to 7.2×10^{-4} cm/s, and from 8.8×10^{-7} to 9.5×10^{-3} cm/s in the upper bedrock. Lesser horizontal hydraulic gradients of 0.01 to 0.07 between the SEPs and the headwater area of South Walnut Creek would result in calculated groundwater flow velocities of 3.2×10^{-6} to 4.2×10^{-4} cm/s in the overburden and 8.8×10^{-7} to 5.5×10^{-3} cm/s in the upper bedrock. Vertical gradients indicate downward flow from the overburden to the bedrock over much of the flow system, with upward flow gradients measured near North Walnut Creek.

The nitrate component of the SPP extends approximately 1,300 feet along the groundwater flow direction from the SEPs to North Walnut Creek (Figure 7). The zone in which nitrate levels exceed 10 mg/L is approximately 1,300 feet wide at its maximum width approximately half-way down the slope from the SEPs. Nitrate concentrations within the delineated zone of contamination range from 10 to 4,900 mg/L, with a zone of the higher concentrations existing in the upper bedrock portion of the flow system. A small zone of nitrate contamination extends in the overburden approximately 1,000 feet from the SEPs to the southeast toward South Walnut Creek. The extent of nitrate contamination in bedrock within this smaller lobe of the plume has not been completely delineated, but is expected to be localized.

The extent of uranium contamination is located within the area encompassed by the nitrate plume. Uranium concentrations in the hillslope aquifer north of the SEPs have been determined at individual sampling locations, but specific zones of contamination or uranium plume concentrations contours have not been delineated. In general, uranium concentrations range from background levels to over 1,000 pCi/L. As with the nitrate distribution, the zone showing the highest uranium concentrations is located in the upper bedrock, but this zone is more localized than the uranium distribution in the overburden.

In summary, the conceptual model for the SPP is one in which, for nitrate and uranium, a zone of groundwater contamination exists in a relatively shallow localized area between a known source location and known discharge locations. The contamination is confined to a hillslope flow system overlying relatively impermeable bedrock. The plume likely remains in the upper portion of the flow system due to the low permeability of the competent bedrock, and the hydraulic flow pattern induced by discharge to North Walnut Creek. Permeabilities of the aquifer materials are relatively low, and flow rates and groundwater fluxes are also correspondingly low, although the steep gradient in the hillslope aquifer does provide a driver for natural flushing of the system. This conceptual model, and the more detailed information contained in the previous sections of this report, will form the basis for the analyses of the remedial alternatives that are to be conducted in the next phase of this investigation.

8 REMEDIAL ALTERNATIVES ANALYSIS

Existing data were reviewed to evaluate their adequacy for developing a conceptual model of the SPP (McLane, 1998), and a preliminary conceptual model for the SPP has been developed (this report). The next phase of work involves the analysis program in which the performance of the conceptual designs for the remedial alternatives will be characterized, and sensitivity of calculated performance to key parameters will be examined. The sections below describe the remedial alternative scenarios that will be analyzed, the models that will be used and the methodology that will be followed in performing the analyses, and the scope for the planned sensitivity analyses.

8.1 Remedial Alternative Scenarios

The performance of the four remedial alternatives currently being considered for the SPP will be analyzed. These alternatives are:

1. No action (baseline conditions: no ITS)
2. Capture of groundwater with managed release
3. Capture of groundwater with treatment and release to Pond A-4
4. Phytoremediation

The no action alternative is being analyzed as a baseline situation for comparison to the capture and phytoremediation alternatives. For each of the active remedial alternatives (2, 3 and 4), the performance of the system is to be analyzed both without and with a cap over the former SEPs in order to simulate future remedial activities which will include the addition of an impermeable cap over the SEPs in 2005. In addition, alternatives 2 and 3 will be analyzed both with and without enhancement of the ITS to determine if groundwater capture of the system can be optimized. Enhancements to the ITS may include keying it to bedrock along its entire length, or extending its length to increase groundwater capture. Thus, the complete set of remedial alternatives to be analyzed, as outlined in the Statement of Work, is:

1. No action (baseline conditions: no ITS)
2. Capture of groundwater with managed release

   a. existing ITS
   b. enhanced ITS
3. Capture of groundwater with treatment and release
   a. existing ITS
   b. enhanced ITS
4. Phytoremediation

For the purposes of this hydrogeologic evaluation, the capture with managed release alternative and the capture with treatment and release alternative are identical with respect to analyses that will characterize containment and mass removal by the ITS. Therefore, the information required by RFETS can be generated by analyzing the remedial alternative scenarios described in Table 4.

Table 4 - Remedial alternative scenarios to be analyzed.

1. Baseline conditions (no ITS)
2. Existing ITS groundwater capture
3. Enhanced ITS groundwater capture
4. Phytoremediation

These four remedial alternative scenarios will form the basis for the analyses that will be performed to characterize the potential performance of the four remedial alternatives currently being considered.

8.2 Analysis Objectives

Specific information regarding the remedial alternatives is required to support the selection process. These information requirements, which will form the analysis objectives for the work to be performed, are specified as:

1. Extraction rate over time (for ITS extraction only; plant root extraction rate will be provided by the phytoremediation team)

2. Groundwater levels over time
3. Groundwater fluxes over time
4. Groundwater quality over time

The analyses performed will be designed to provide, as output, the information required by RFETS. In addition, the selection of the final alternative will be partly based on the maximum concentration of compounds as set forth in the RFCA. The established water quality standard for nitrate is 10 mg/L, with an interim standard of 100 mg/L in place between 1999 and 2006. The current water quality standard for uranium is 10 pCi/L, but may be increased if a health-based standard (most recently proposed at 30 pCi/L) is adopted (RMRS, 1997c).

8.3 Analysis Methodology

The analysis program will use one-dimensional and two-dimensional analytical and numerical models to analyze the future performance of the remedial alternative scenarios listed in Table 4. Appropriate simplifications will be made to the SPP flow system to streamline the analyses and to support relative comparisons of the identified scenarios. Preliminary analyses will be conducted to screen the proposed remedial alternatives. Additional in-depth analyses may be conducted for selected alternatives. Output will be generated for each remedial alternative scenario, and provided in an alternatives analysis report to support further evaluation of the proposed remedial alternatives. In addition, sensitivity analyses will be performed to provide information on the effect of key parameters on calculated alternatives' performance. The sections below describe the models that have been selected to perform the analyses, the phased technical approach for the screening and in-depth portions of the remedial alternatives analyses, and the sensitivity analyses that will be conducted.

8.3.1 Selected Models

Two types of models will be required to perform the analyses that will meet the objectives defined in Table 4. Groundwater flow models will be required to calculate the ITS extraction rate, groundwater levels within the SPP hillslope aquifer system, and fluxes of groundwater within the aquifer and to nearby surface water bodies. Plume flushing and/or mass transport models will be required to calculate the water quality within the SPP hillslope aquifer system.

TWODAN (Fitts, 1997), a two-dimensional analytical flow model, has been selected to perform scoping analyses of ITS capture in the horizontal plane. TWODAN can provide highly refined depictions of flow patterns in the immediate vicinity of groundwater sinks such as trenches, and can also be used in vertical profile mode to present a cross-sectional view of the water table location and flow lines in the flow system.

MODFLOW-SURFACT (HydroGeoLogic, 1996) was selected for two-dimensional flow analyses of the SPP hillslope aquifer system in the vertical plane. Although SURFACT is a three-dimensional numerical model, it will be set up to represent a vertical cross-section extending from the SEP area downgradient along the axis of the plume being analyzed. SURFACT is capable of calculating water levels within the unconfined SPP aquifer, including the location of and fluxes at seepage face zones. It is also capable, when interfaced with MODPATH (Pollock, 1994) of performing particle tracking to delineate flow paths through the aquifer and groundwater velocities that can be used to estimate rates of plume migration and flushing.

Both TWODAN and SURFACT permit the specification of losses from the water table surface, which will be used in these analyses to simulate losses due to evapotranspiration for the phytoremediation scenarios.

PRINCE (Waterloo Hydrogeologic, 1994), a two-dimensional analytical transport model, has been selected to perform scoping analyses of dissolved mass transport within the SPP. SURFACT also contains a mass transport capability that can be used to simulate the removal of plume mass along a selected vertical profile as the model will be configured in this application. Plume mass removal rates, aquifer water quality changes through time, and mass flux from groundwater to surface water will also be analyzed using one or more of the analytical plume flushing models described in the technical literature (Zheng et al., 1991). These models, which will be developed using spreadsheets, will be based on initial plume conditions and on the groundwater flux rates calculated by the vertical profile groundwater flow models.

If calculations are required for soil infiltration and vertical water and mass flux in the soil zone, the HELP (Schroeder et al., 1994) and HYDRUS (Vogel et al., 1996) models will be employed. HELP is a widely used one-dimensional model capable of determining infiltration and runoff components for various soil zone hydrologic conditions. HYDRUS is a one-dimensional saturated-unsaturated flow and mass transport model that provides the capability to simulate water and mass flux in the vadose zone, and to calculate the location of the water table, considering both surface infiltration from continuous or discrete precipitation events and the effects of root zone water extraction.

8.3.2 Technical Approach

A preliminary round of screening analyses will be conducted for each of the four remedial alternative scenarios listed in Section 8.1. Information will be generated regarding ITS extraction rate, groundwater levels, groundwater fluxes, and groundwater quality. Based on the results of the screening analyses, a subset of the scenarios may be selected for a second phase of more detailed analyses. Sensitivity analyses will be performed during the second phase of analyses to characterize the effects of changes in input parameters on the performance of the analyzed alternative scenarios.

8.3.3 Analysis Program

The following sections describe the second phase of the analysis program including the basic engineering analyses for the selected subset of remedial alternative scenarios, and sensitivity analyses for key parameters.

Selected Scenario Analyses

During phase two of the analysis program, a more comprehensive and in-depth set of analyses will be performed for a selected subset of remedial alternative scenarios. Additional refinements may be made to the models used in the first round of analyses, and a greater level of integration will be imposed on the models that will be linked to perform each analysis. These refinements and enhanced linkages will require greater time to perform each analysis, but will result in additional accuracy and detail in the analysis results.

Sensitivity Analyses

Upon completion of the phase two analyses for the selected remedial alternative scenarios, sensitivity analyses will be conducted for key parameters. Key parameters will be identified, and a range of values will be identified for each key parameter. Sensitivity analyses will be performed by varying each parameter independently over its identified range to characterize its effect on the output values of interest. Sensitivity analyses results will be reported in the alternatives analysis report.

8.3.4 Interactions with Other Teams

During the analyses of the remedial alternatives scenarios, other teams will be consulted to obtain or exchange data and information. Data will be exchanged with the CH2M Hill phytoremediation study team prior to and during the analyses of the phytoremediation alternative. The modeling results will be reviewed by the Actinide Migration Panel for consistency.

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10 LIST OF ACRONYMS

IA	Industrial Area
ITPH	Interceptor Trench Pump House
ITS	Interceptor Trench System
MCL	Maximum Contaminant Level
MST	Modular Storage Tank
RFCA	Rocky Flats Cleanup Agreement
RFETS	Rocky Flats Environmental Technology Site
SEP	Solar Evaporation Pond
SPP	Solar Ponds Plume
VOC	Volatile Organic Compound